Introduction: The Past Is Prologue

Maintaining a Tradition of Excellence and Innovation

For more than a quarter of a century, the National Science Board's *Science & Engineering Indicators* report series has been a chronicler of key trends in science and engineering research and education. As the United States begins the transition into the 21st century and into a knowledge-based economy, it is worthwhile to examine the significant changes in the science and technology (S&T) enterprise that characterize the current period. Many of the issues faced at the time of the Board's first report, *Science Indicators – 1972*, endure. Also, important aspects of the future will be at least partially determined by the S&T resources—both human and financial—in which the Nation has already invested.

An analysis of historical trends is possible due to the foresight of science policy leaders in the past. The collection and analysis of quantitative information as a basis for policy and decisionmaking was an integral component of the National Science Foundation's (NSF's) mandate from the outset. In preparing NSF's first full-year budget for fiscal year 1952, the National Science Board allocated $1 million of its approximately $13.5 million request for a survey of the Federal Government's financing of research and development (R&D). In 1953-54, NSF extended its surveys beyond the Federal Government to encompass research support and performance in industry, colleges and universities, and other organizations. At about the same time, it initiated the first in a series of human resource surveys.

"Through these studies," as NSF's 1957 annual report emphasized, "the Foundation has provided a new kind of measurement of national economic strength." This quote from a document published over four decades ago is as appropriate today as it was then. Many of the indicators that were developed at that time are still viewed as essential ways of measuring national S&T capabilities and economic strength. As times change, the need for additional data and indicators has evolved, along with the need for greater elaboration and disaggregation of many of the previous data trends. This information and analyses enable a better understanding of the various characteristics of the S&T enterprise, including who the various participants are, patterns of collaboration, and impacts on the broader society.

The 1957 annual report, which included a chapter summarizing NSF's survey activities and highlighting future survey plans, stressed the centrality of this work to the agency's mission. In fulfilling its statutory responsibility to develop and encourage the pursuit of a national policy for the promotion of basic research and education in the sciences, the National Science Foundation developed and has continued its surveys of the U.S. R&D effort in various sectors of the economy. These studies and surveys provide a solid basis for analyses, conclusions, and recommendations concerning S&T resources.

Responding to Expanding User Needs

The National Science Foundation Act of 1950, as amended, states that the Board is responsible for rendering to the President for submission to Congress in each even-numbered year a report on indicators of the state of science and engineering in the United States (Sec. 4 [j][1]). The current issue, *Science & Engineering Indicators – 1998*, is the 13th in the biennial series. This important national and international data resource is part of the Board's larger responsibility in the area of national science and technology policy.

The Act further authorizes the Board to advise the President and Congress on matters of science and engineering policy (Sec. 4 [j][2]). In accord with this broader obligation, the Board has determined to prepare a series of occasional papers commenting on selected trends in the *Indicators* report to focus attention on issues of particular current and long-term concern regarding the Nation's science and engineering enterprise.

Governments at all levels and nongovernmental organizations in the United States as well as in many other countries are increasingly concerned with accountability and benchmarking activities. With the advent of the Government Performance and Results Act (GPRA), the development of reliable output and impact indicators for inclusion in the *Science & Engineering Indicators* report series has become even more important. *Science & Engineering Indicators – 1998* provides data and information that can be useful as a general framework or source of complementary information as various organizations develop their own specific performance indicators.

The conceptualization of new types of quantitative information to characterize emerging aspects of the science and engineering enterprise and their impacts has had a significant influence on the evolution of indicators methodology itself. *Science & Engineering Indicators – 1998* continues this tradition with a new chapter titled "Economic and Social Significance of Information Technologies." There is an increasing need to understand and communicate more effectively and efficiently the contributions and outcomes of science and technology. Measurement of the economic and social impacts of S&T is a special challenge particularly for rapidly developing areas epitomized by information technologies. The Board believes that this new chapter, which addresses both positive and negative aspects of information technologies, makes a significant contribution toward synthesizing and crystallizing what is currently known about this important topic.

Beginning in the late 1950s, NSF's annual reports devoted increasing attention to the international context of U.S. science and engineering, particularly following the launching of Sputnik I by the Soviet Union in October 1957. Reflecting the importance of comparative international information, *Science Indicators – 1972* included data on R&D expenditures of several major foreign countries. Coverage of international topics has been enhanced with each succeeding edition of the report, as has its international readership. Noting the increase in the globalization of science and technology and the increased interdependence of the world's economies, the Board decided to make international comparisons and global trends a major theme of the *Science & Engineering Indicators – 1998* report. The growing availability of internationally comparable data is—in large measure—the result of close working relationships developed over many years between NSF staff and their counterparts in other countries who are also engaged in the collection and analysis of indicators data. Several multinational organizations also contribute substantially to making such data available. These include the Organisation for Economic Co-operation and Development (OECD), the United Nations Economic, Scientific, and Cultural Organization (UNESCO), the European Union (EU), the Pacific Economic Cooperation Council (PECC), the Asian Pacific Economic Cooperation (APEC), the InterAmerican InterIberian Science and Technology Network (RICYT), and the Organization of American States (OAS).

In recognition of the increasing attention worldwide to the importance of developing S&T indicators, as well as NSF's international leadership in this effort, NSF and OECD organized an international workshop on the Uses of Science and Technology Indicators for Decisionmaking and Priority Setting; this was held at NSF headquarters from September 7-9, 1997. Claudia Mitchell-Kernan, Chairman of the Science & Engineering Indicators Subcommittee, represented the National Science Board as a co-host of the meeting and stressed the growing importance of international comparisons. The representatives from 28 countries and six international organizations who participated in the event strongly concurred.

Today, the need for quantitative data to assist in decisionmaking is even stronger than it was when the Board first began this effort. The U.S. science and technology enterprise is in transition. The country is changing its priorities for R&D investment and faces budgetary constraints in many sectors. Additionally, the United States—and the rest of the world—is part of an increasingly global economy. Science and engineering activities have always had a global dimension, but this is now intensifying. *Science & Engineering Indicators – 1998* not only emphasizes international comparisons, but also provides data and analyses related to all of the above important topics.

With the growth of the science and engineering enterprise over the past decades and of public recognition of its importance to economic and social well-being, the audience for the *Science & Engineering Indicators* reports and the need for new data and analyses have expanded. To make these data more accessible to this growing audience, the entire report is now available in electronic format (<<http://www.nsf.gov/sbe/srs/stats.htm>>) as well as in hard copy.

Additional New Features of This Report

In the tradition of previous reports, *Science & Engineering Indicators – 1998* contains a number of new features and indicators. In addition to enhanced international comparisons and a new chapter on the significance of information technologies, these new features include the following:

- ♦ improved international performance indicators of precollege science and mathematics education, curricula, and teacher preparation;
- ♦ increased attention to and new indicators of international S&T mobility, such as foreign participation in the S&T activities of the Nation, international engineering programs in the United States, and the reverse flow of scientists and engineers to Asia;
- ♦ enhanced coverage of the situation of recent graduates and postdoctoral scientists and engineers;
- ♦ coverage of the restructuring of the defense industry and its impact on the Nation's S&T enterprise;
- ♦ enhanced and new indicators of intersectoral and international collaborations/partnerships;
- ♦ expanded coverage of the service sector;
- ♦ new venture capital indicators;
- ♦ new indicators of Internet and World Wide Web use;
- ♦ indicators of the impacts of information technologies on science, mathematics, and engineering education, including some attention to distance learning in higher education;
- ♦ potential future requirements for information technology employment; and
- ♦ analyses of access to the latest information technologies and their potential impact on participation in science and mathematics careers.

Another new feature of *Science & Engineering Indicators – 1998* is the inclusion of several reflections on future pressures and possible trends, coupled with the identification of a number of important data and information gaps that deserve continuing attention.

The report Overview is organized around four cross-cutting themes that encapsulate significant trends in the transition into the 21st century. Taken together, these trends exemplify both the condition of the science and engineering enterprise in the United States and the links between science and engineering activity and U.S. society more broadly as the country prepares for a new century. These trends are:

- **Increasing globalization of science, technology, and the economy.** Other countries besides the United States are investing in financial and human resources for science and technology, recognizing that such investments are essential underpinnings for social and economic well-being in the global economy. Individual scientists and engineers, industrial firms, and academic institutions are taking advantage of the increasingly international character of S&T, as witnessed by the enhanced international mobility of the S&T workforce, international coauthorship of scientific publications, the development of international industrial alliances, and the global flow of technological know-how.
- **Greater emphasis on science and engineering education and training.** Many countries, including the United States, recognize the importance of providing an excellent education to their population in a global, knowledge-based economy. At the professional level, universities in the United States and elsewhere face the challenge of introducing greater flexibility and breadth into their curricula so as to improve the employment prospects of their students at both the undergraduate and graduate levels. More broadly, the Nation as a whole faces the challenge of ensuring that its diverse workforce will possess sufficient technological literacy, and its citizenry sufficient knowledge and understanding of S&T and its socioeconomic impacts, to address the requirements of the new century.
- **Structural and priority changes in the science and engineering enterprise.** The decreasing involvement of the Federal Government relative to private industry in providing financial support for the Nation's R&D effort, evident since the beginning of the decade, persists. The federal role remains essential, however, in the support of basic research in the academic sector and in the integrally linked education of the country's science and engineering workforce. Even as the role of industry in supporting R&D has become more prominent, the structure of research in industry itself is changing, as is evident from the increasing prominence of R&D in the service industries. Industrial R&D support remains most heavily concentrated in applied research and development, as opposed to basic research. That private industry recognizes the importance of U.S. colleges and universities to the national enterprise is evident from the increasing links between the industrial and academic research sectors.
- **Increasing impact of science and technology on our daily lives.** The impact of S&T on our daily lives is profound—however difficult to track or quantify. The changes brought about in the workplace, schools, and homes by information technologies may be the most obvious case in point. Data characterizing many of the more important effects are presented in chapter 8 of this report, "Economic and Social Implications of Information Technologies."

None of the cross-cutting themes identified as exemplary of the U.S. science and engineering enterprise in this, the penultimate edition of *Science & Engineering Indicators* in the 20th century, is particularly novel. Indeed, these themes have been apparent—at least in retrospect—in the results of the surveys that NSF has been carrying out since the 1950s. These themes will no doubt continue to be important in the year 2000 and beyond.

A Continuing Responsibility

A decade ago, it would have been all but impossible to predict, in any detail, the ubiquitousness of information technologies in our lives. By the same token, it is all but impossible to predict the effect of current S&T activity on our daily lives at the end of the first decade of the new century. One of the few predictions that the Board *can* make with any certainty is that the four cross-cutting themes described above will remain important after the turn of the century. It is also apparent that no ultimate solutions will have been found to the many important S&T-related issues that the Nation's decisionmakers and citizenry will face. Nevertheless, the thrill of discovery, the quest for knowledge, and the need to apply such knowledge to human problems will remain.

The *Science & Engineering Indicators* reports are intended to provide the factual information on S&T resources needed by policymakers in government, industry, and academia in weighing policy options. The National Science Board has long provided high-quality quantitative information relevant to S&T policy issues through its biennial *Science & Engineering Indicators* reports. The Board considers these reports to be a sturdy basis on which to build. It routinely revisits their format, the data and indicators they contain, and the implications of the trends identified. Interactions with the scientific community and the public provide opportunities to examine the implications of the data and anticipate what data and indicators will be needed in the future. The Board welcomes the opportunity to develop new and refined indicators to document the evolution of the U.S.—and global—science and engineering enterprise in the final years of the 20th century and beyond.

Overview: Science and Technology in Transition to the 21st Century

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"The force of scientific and technological innovation is helping to fuel and shape that new economy, but its impact goes beyond. These investments have surely paid off in higher paying jobs, better health care, stronger national security, and improved quality of life for all Americans. They are critical to America's ability to maintain our leadership in cutting-edge industries that will power the global economy of the new century."

President William J. Clinton

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Science, technology, and economies are becoming increasingly global. This is one of the major trends characterizing the transition into the 21st century. U.S. investments in science and technology (S&T) should be viewed in a global context. The United States and many other countries are investing in S&T capabilities, with both financial support and human resource development. Science & engineering (S&E) students and personnel are internationally mobile. Scientific and technological collaboration and alliances are increasing in both academia and industry. The most effective form of S&T transfer is "people embodied," but technological know-how is also transferred through direct investment, patenting activity, the sale of intellectual property, and trade in technology-embodied products. The following highlights demonstrate the globalization of science, engineering, technology, and the economy in terms of growth in worldwide S&T investments and increased international interactions.

Many countries are investing in science and technology as a key economic strategy.

- The U.S. economy continues to rank as the world's largest, and the United States (all sectors combined) also spends the largest amount for research and development (R&D). Similarly, most other industrialized and developing countries are investing in R&D. European countries have long done so, but now countries in Asia and the Americas are also putting special emphasis on increasing both human and financial investment in S&T.
- Expenditures on R&D performed in the United States exceeded $200 billion for the first time in 1997. The United States accounts for about 44 percent of the industrial world's R&D investment and almost as much as the other G-7 countries (Japan, Germany, the United Kingdom, France, Italy, and Canada) combined. In civilian R&D, however, the expenditures of these six countries totaled 18 percent more than nondefense R&D spending in the United States.

S&E education is increasing globally.

- Many countries have invested in training scientists and engineers. From the mid-1980s to the mid-1990s, the number of degrees in higher education in science and engineering increased rapidly in Asia and Europe. Trend data from selected Asian countries show great increases in the number of first university degrees in science and engineering fields for China, India, Japan, South Korea, Singapore, and Taiwan. Between 1975 and 1995, the total number of degrees in the natural sciences earned by students from these countries doubled; those in engineering almost tripled.

- From 1975 to 1992, the Western European countries collectively more than doubled their annual production of first university degrees in science and engineering. This increase in S&E degree production occurred despite a declining pool of college-age students in Europe. Participation rates in S&E degrees increased to more than offset the declining population.

- Europe leads the United States and Asia in S&E doctoral degree production. In 1995, doctoral degrees awarded in S&E fields by Western and Eastern European (including Russia) institutions totaled 45,647—about 60 percent higher than the North American level and almost three times as many as the number recorded for Asian countries.

- The global diffusion of S&E education has implications for the U.S. higher education system. Other countries' increasing capacity to educate students in advanced levels of science and engineering may be one reason for the decline in foreign student enrollment in U.S. engineering programs. Additionally, the continuing expansion of global capacity for S&E education may affect all nations, since it indicates an increasing potential for technological and economic development worldwide.

The S&T workforce is becoming more global.

- The number of scientists and engineers engaged in research and development has increased in many countries. The U.S. share of the total numbers of R&D scientists and engineers in the G-7 has fallen slightly from 48 percent in 1981 to 45 percent in 1993. Japan had 80 scientists and engineers engaged in R&D for every 10,000 persons in the labor force in 1993, compared with 74 for the United States.

- In the past decade, foreign students have accounted for the large growth in S&E doctoral degrees in U.S. universities. For the period 1992-96, the percentage of foreign doctoral recipients planning to remain in the United States increased: more than 68 percent planned to locate in the United States, and nearly 44 percent had firm offers to do so. Stay rates differ considerably by nationality. In 1996, more than half (57 to 59 percent) of S&E doctoral recipients from China and India receiving their degrees from a U.S. institution had firm plans to stay. A smaller percentage of those from South Korea and Taiwan (24 and 28 percent, respectively) accepted employment offers in the United States.

- International mobility is a characteristic of postdoctoral researchers. From 1990 to 1994, U.S. universities provided slightly more than half of their postdoctoral appointments to non-U.S. citizens. Another indicator of international mobility is the proportion of foreign-born faculty in U.S. higher education. In 1993, 37 percent of U.S. engineering professors and 27 percent

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"Science and art belong to the whole world and before them vanish the barriers of nationality."

JOHANN WOLFGANG VON GOETHE

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of U.S. mathematics and computer science professors were foreign-born. These faculty members are mainly from Asia and Europe, with the largest numbers coming from India, China, the United Kingdom, Taiwan, Canada, and South Korea.

- In 1993, almost a quarter (23 percent) of doctoral scientists and engineers in the United States were foreign-born. More than a third of these (34 percent) received their S&E doctorates from foreign institutions. In general, the percentage of immigrants is highest in fields with very good labor market conditions, such as engineering and computer sciences. The highest proportion of foreign-born holders of doctorates was in civil engineering (51 percent); the lowest was in psychology (9 percent).

- Some U.S. doctorate recipients go abroad. A lower-bound estimate of U.S.-born Ph.D. graduates residing abroad in 1995 is 13,900 (3.3 percent of the total). If those with U.S. citizenship or permanent residency at the time of their degrees are included, this rises to 19,600 (4.1 percent of the total).

Scientific publications are increasingly international in character.

- Since 1981, the overall number of articles published in a set of the world's influential S&T journals rose by almost 20 percent, compared with a rise of 8 percent in articles attributed to U.S. authors. This increase coincided with the strengthening of S&T capabilities in several world regions. Europe increased its share of published output from 32 percent in 1981 to 35 percent in 1995, reaching a higher share than that of the United States. Asia's share rose from 11 to 15 percent over the period.

- International collaboration on scientific publications is increasing, reflecting the globalization of science. In 1995, half of the articles in a set of journals covered by the Science Citation Index had multiple authors, and almost 30 percent of these involved international collaboration. A steadily growing fraction of most nations' papers involved coauthors from different nations. From 1981 to 1995, while article output grew by 20 percent, the number of articles with multiple authors rose by 80 percent, and the number with international coauthors by 200 percent. These trends affected all fields.

- For almost every nation with strong international coauthorship ties, the number of articles involving a U.S. author rose strongly between 1981 and 1995. Nevertheless, during this same period, many nations broadened the reach of their international collaborations, particularly within

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"Every great advance
in science has issued from
a new audacity of imagination."

JOHN DEWEY

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geographical regions, causing a drop in the U.S. share of the world's internationally coauthored articles. In the Asian region, collaboration particularly involved China and the newly developing industrial countries.

- Citation patterns also mirror the global nature of the scientific enterprise, as researchers everywhere extensively use and cite research findings from around the world. U.S. scientific and technical articles as a whole are cited by researchers in virtually all mature scientific nations in proportions greater than the U.S. share of world output in chemistry, physics, biomedical research, and clinical medicine. U.S. articles in the remaining fields tend to be cited at or slightly below the U.S. share of world output.

Industrial firms are developing international alliances.

- Industrial firms are using global research partnerships as a means of strengthening core competencies and expanding into technology fields that are crucial to maintaining market share. Since the mid-1980s, companies worldwide have entered into over 4,000 known multi-firm alliances involving strategic technologies. More than one-third of these were between U.S. firms and European or Japanese firms. Most of the alliances were created to develop and share information technologies.

Foreign patenting activity demonstrates the global nature of technology.

- Foreign patenting in the United States is also strong and highly concentrated by country of inventor. Five countries—Japan, Germany, France, the United Kingdom, and Canada—accounted for 80 percent of foreign-origin U.S. patents. Several newly industrialized economies, notably Taiwan and South Korea, dramatically increased their patent activity in the late 1980s and continue to do so.
- Americans successfully patent their inventions around the world. U.S. inventors received more patents than other foreign inventors in neighboring countries—Canada and Mexico—and in distant markets such as Japan, Hong Kong, Brazil, India, Malaysia, and Thailand.

Trends in royalties and fees indicate global flows of technological know-how.

- The United States is a net exporter of technological know-how; royalties and fees received from foreign firms have averaged three times those paid to foreigners by U.S. firms for access to their technology. Japan is the largest consumer of U.S. technology sold as intellectual property, and South Korea is the second largest.

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"The world is changing more quickly than ever. Each of us sees the speed and force of those changes around us every day, in ways we perceive as wondrous, elegant and profound – even sometimes, a little overwhelming."

Richard N. Zare
Chairman
National Science Board

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"A nation which depends upon others for its basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill."

VANNEVAR BUSH

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Foreign direct investments in R&D are increasing and demonstrate S&T globalization

- Substantial investment in R&D is made by U.S. firms abroad as well as foreign firms in the United States. From 1985 to 1995, U.S. firms increased their R&D investment abroad three times faster than their company-funded R&D performed domestically.
- R&D funding in the United States by foreign companies grew an average of 12.5 percent per year from 1987 to 1995, even after adjusting for inflation. Foreign-sourced R&D performed in the United States is now roughly equivalent to U.S. companies' R&D investments abroad. More than 670 foreign-owned R&D facilities are located in the United States.
- Most of the foreign international investment in R&D flowing into the United States is from Europe and Japan and is concentrated in the drugs and medicines, industrial chemicals, and electrical equipment industries.

International trade in technology products is another indicator of S&T globalization.

- The United States continues to be the leading producer of high-tech products, responsible for about one-third of the world's production of such products. During the 1980s, Japan rapidly enhanced its stature in high-tech fields, but by 1995, U.S. high-tech industries regained world market share lost during the previous decade.
- Between 1990 and 1995, three of the four science-based industries in the United States that form the high-tech group—computers, pharmaceuticals, and communications equipment—gained world market share. Aerospace was the only U.S. high-tech industry to lose market share in the 1990s. The U.S. trade surplus in software technology doubled, and aerospace technologies produced large—albeit declining—trade surpluses for the United States.

Many countries are emphasizing science, math, and engineering education as essential to achieving economic and societal goals both now and in the 21st century. There is an increasing realization of the importance of education and knowledge to economic growth. Such education is seen as important not only for researchers but also for a diverse, technologically literate workforce and for an educated and informed citizenry. Examining, updating, and improving the U.S. education system from K-12 through to graduate school is a major national priority as we enter the next century. Concerns have been expressed regarding the employment prospects of science and engineering graduates, and universities are examining ways to make graduate education broader, more flexible, and relevant to present and future economic demands. Current issues include the role of the Federal Government in funding graduate education, the further integration of research and education, and the importance of attracting and retaining students from all backgrounds into science and engineering fields. The following highlights provide some information on these topics.

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"The path to any nation's scientific and technological capability is an early, strong, and continuous math and science education for each and every student. The earlier it begins and the longer it lasts, the better for the individual and the nation."

Neal Lane
Director
National Science Foundation

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Progress has been made in precollegiate math and science education, but more needs to be done—especially in mathematics.

- In national assessments of math and science learning, students are performing as well as, if not better than, the students of 25 years ago. Nine-year-olds and 13-year-olds are scoring higher on mathematics and science tests than they did in 1973, while performance of 17-year-olds has remained about the same.
- In the United States, there is little difference in the mathematics and science proficiency of girls compared with boys on national assessments of education progress. As of 1996, however, large differences remain at all grade levels in the achievement scores of black and Hispanic students as compared with whites and Asians/Pacific Islanders. Native Americans generally scored closer to the national average than did blacks or Hispanics, but lower than whites.
- In a 1995 international comparative study on mathematics and science achievement, U.S. students performed comparatively better in science than in mathematics and better at the fourth grade level than at the eighth grade level.
- U.S. fourth graders were significantly surpassed in science performance only by students in South Korea. Students in Japan, the Netherlands, Australia and Austria also performed well at this level. U.S. eighth grade students scored just above the international average in science, scoring lower than students from Singapore, South Korea, Japan, and the Czech Republic.

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"Statistical thinking will one day be as necessary for efficient citizenship as the ability to read and write."

H.G. Wells

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- Unlike in science, performance in mathematics at the fourth grade level in a 1995 international test showed U.S. students behind those of Singapore, South Korea, Japan, and Hong Kong. U.S. eighth graders answered just over half of the items on the mathematics assessment correctly and scored below the international average. Eighth grade students in Singapore, Japan, South Korea, Hong Kong, Flemish-speaking Belgium, and the Czech Republic performed the best.
- Since the early and mid-1980s, the proportion of students taking advanced mathematics and science courses in high school has greatly increased. These gains often include students from underrepresented groups. Nonetheless, the achievement of U.S. students in mathematics has shown only slight gains over time, and there remains a large proportion of students unable to demonstrate anything more than basic levels of knowledge, particularly at grade 12.
- U.S. mathematics and science textbooks contain many more topics and much repetition of material compared with those of other countries. In addition, there is evidence that in the United States, eighth grade mathematics is pitched at a lower level than in higher achieving countries. U.S. students are still working on "high-end" arithmetic while their peers in other countries are studying algebra and geometry.
- The vast majority of U.S. elementary school teachers earn college degrees in education rather than in specific disciplinary areas. High school teachers are much more likely than middle or grade school teachers to possess science and mathematics degrees. Teachers are also frequently assigned to teach classes outside their fields, especially in middle school. The problem is particularly acute in mathematics.

Students often need remedial math and science preparation when entering higher education, but they are succeeding in getting S&E degrees at all levels.

- As students enter college, problems in math and science preparation are obvious. The percentage of freshmen reporting a need for remedial work in math and science has remained high, particularly for women and minorities. In 1995, of those freshmen planning to major in science or engineering, over 16 percent of the males and over 26 percent of the females thought they would need remedial work in mathematics. These data are based on students' self-evaluations and may also reflect various levels of confidence.
- Nevertheless, the number of earned bachelor's degrees in S&E from U.S. institutions has increased from over 307,000 in 1981 to 378,000 in

1995. By the mid-1990s, more than 5 percent of the college-age population had completed a bachelor's degree in a field of natural science or engineering (NS&E).

- Enrollment in undergraduate programs by underrepresented minorities has increased for over a decade, and this trend accelerated in the 1990s. In 1995, however, only about 2 percent of black and Hispanic college-age youth earned a bachelor's degree in an NS&E field.
- Total enrollment in U.S. graduate S&E programs grew for almost two decades and has now begun to shrink. Graduate enrollments of foreign students and white males have dropped. A long trend of steady increases in the enrollment of full-time graduate students whose primary source of support was the Federal Government also ended in 1995.
- At the master's degree level, science and engineering overall showed a great increase in the numbers of earned degrees throughout the 1980s, with the trend becoming even stronger in the 1990s. The recent growth is mainly in the social sciences and engineering, with relatively stable numbers in the natural sciences, mathematics, and computer sciences. The proportion of master's degrees in S&E fields earned by women and minorities has increased over the last two decades.
- The number of doctoral degrees in engineering, mathematics, and computer sciences doubled from 1985 to 1995. Much of this growth involved foreign doctoral recipients; the number of doctoral degrees they earned in S&E fields doubled from over 5,000 in 1986 to over 10,000 in 1995.

Increased attention is going to the extent to which research and education are integrated and the role of the Federal Government in supporting both R&D and graduate students.

- The Federal Government is the main source of support for graduate students via several support mechanisms. A majority of traineeships in both private and public institutions (53 percent and 73 percent, respectively) are financed primarily by the Federal Government, as are 60 percent of the research assistantships in private institutions and 47 percent in public institutions.
- The prevalence of research assistantships as the primary mechanism of support for full-time graduate students in science and engineering has increased considerably. Research assistantships were the primary support mechanism for 66 percent of the students whose primary source of support was from the Federal Government in 1995, compared with 55 percent in 1980.

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"Ignorance is the night of the mind,
a night without a moon or star."

CONFUCIUS

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"Perhaps the most profound discovery
of the 20th century is the
sudden confrontation with
the depths of our ignorance."

LEWIS THOMAS

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♦ The National Institutes of Health and National Science Foundation are the two federal agencies that have been the primary sources of support for full-time S&E graduate students relying on research assistantships as their primary support mechanism. Nonetheless, other agencies have varying and important impacts on graduate education in specific fields.

♦ Research assistantships are more frequently identified as a primary mechanism of support in the physical sciences, the environmental sciences, and engineering than in other disciplines. They account for less than 20 percent in all the social sciences, mathematics, and psychology.

Graduate education is being reexamined to determine its appropriateness for labor force needs in the future.

♦ Although there were many changes in labor market conditions for specific science and engineering fields, overall labor market conditions were similar in 1993 and 1995. Overall unemployment rates for science and engineering Ph.D.-holders were 1.6 percent and 1.5 percent, respectively.

♦ For recent Ph.D. graduates, the unemployment rate went from 1.7 to 1.9 percent. Only 2.4 percent of recent science and engineering Ph.D. recipients reported working in a non-S&E job unrelated to their fields.

♦ Measured by the percent reporting that they were involuntarily working outside their fields (IOF rate), the disciplines where recent Ph.D. graduates were having the most difficulties in 1995 were political science (11.2 percent), mathematics (9.3 percent), sociology/anthropology (9.1 percent), geosciences (6.8 percent), and physics (6.7 percent). Recent Ph.D. graduates in the biological sciences do very well by this measure, with only a 2.8 percent IOF rate, but other measures suggest a drop in the availability of tenure-track positions for recent biological science graduates.

♦ Most science and engineering Ph.D.s are currently employed outside of academia. Looking at entire career histories, only a little over half of scientists and engineers—even at the doctorate level—were employed in academia at some point in their careers.

♦ An estimated 26,900 Ph.D.s who earned their doctorates in the preceding three years entered academic employment in 1995. But the meaning of "academic employment" has changed for these young doctorate-holders. Fewer than 45 percent had regular faculty appointments, compared with over 75 percent in the early 1970s, while the proportion in postdoctorate positions rose from 13 to 40 percent.

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"There is no higher or lower knowledge, but only one, flowing out of experimentation."

Leonardo da Vinci

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"The value of achievement lies in the achieving."

Albert Einstein

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- Of scientists and engineers in postdoctorate positions in 1993, only 12.1 percent were in faculty positions in a tenure track in 1995; 41.6 percent were still in postdoctorate appointments. Despite this, the length of time being spent in postdoctorate positions appears only slightly greater than that reported retrospectively by those currently in mid-career.
- While most individuals in postdoctorate positions in 1995 reported additional training and other customary reasons for accepting their appointments, 17.1 percent said they were in a postdoctorate because other employment was not available. This rises to 29.3 percent in geosciences and 26.8 percent in physics.

S&E human capital development in the United States continues to show significant unevenness across socioeconomic groups.

- The number of women with doctorates in science and engineering who held academic positions increased to 52,400 in 1995. This represented a new high of 24 percent of total academic employment of these highly trained personnel. Women remained highly concentrated in the life and social sciences and psychology.
- Minority S&E Ph.D. employment in academia continued to grow, reaching 35,300 in 1995, but stayed at low levels for some groups. The 12,800 members of underrepresented groups—black, Hispanic, Native American, and Alaskan Native—accounted for 6 percent of academic doctoral scientists and engineers, up from 2 percent in 1973. Asian employment in 1995 stood at 22,500, 10 percent of the total, up from 4 percent in 1973.
- Women and members of minority groups have tended to enter academic employment at or above their share of recently awarded science and engineering doctorates. Among recent Ph.D.s in academic employment (those with doctorates awarded in the preceding three years) women and underrepresented minorities were employed in rough proportion to their share of newly awarded doctorates to U.S. citizens and permanent visa-holders, Asians were represented well in excess of their share of new Ph.D.s in science and engineering (although many of these are foreign-born).
- In the overall S&E workforce, minorities, except for Asians, are still a very small proportion of employed scientists and engineers in the United States. Asians, with 4 percent of the U.S. population, represented 10 percent of all S&E workers in 1995. Blacks and Hispanics were 3.4 percent and 2.8 percent of the S&E workforce in 1995, well below their shares of the U.S. population (12 percent and 9 percent respectively). Asians, 84 percent of whom are foreign-born, are the best represented minority group

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"In the highly competitive, knowledge-rich, information-intensive, global economy, every individual, no matter what gender, color of skin, or disability, must be provided the opportunity and indeed encouraged to pursue their interests and to develop their talents in science and technology whether it be as a career choice or to be able to exercise full citizenship in the technology and information age we have entered.
Our nation can no longer afford to underinvest in their potential or to have science and technology-illiterate citizens in its democracy."

John Gibbons
Director
Office of Science
and Technology Policy

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in mathematics and computer sciences, physical sciences, life sciences, and engineering, each at around 10 percent. The underrepresented minorities—blacks, Hispanics, and Native Americans—are most likely to enter social sciences and least likely to enter physical sciences.

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"I spend money on war because it is necessary, but to spend it on science, that is pleasant to me."

George III

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The nation's S&E enterprise is undergoing changes in structure and priorities as we prepare to enter the next century. Major changes are taking place in sector roles in the funding of research and development. The proportion of the Nation's R&D funds provided by the Federal Government has decreased, but the role of the Federal Government is still essential in the areas of basic research and education. Priorities are changing, with defense R&D decreasing in importance and life sciences and health receiving increased funding and attention. The industrial sector provides a majority and increasing share of national funding for research and development. This has implications for the character of activities supported because industrial R&D is primarily concentrated in development and applied research, rather than basic research. In many countries, direct funding is supplemented by R&D tax credits and other indirect mechanisms. Science and technology are increasingly linked, and the role of partnerships and alliances has increased between sectors, within sectors, and internationally. The service sector has a more important profile than in the past. Information technologies are an important driver for the economy and are making an economic and social impact that are just beginning to be understood.

R&D funding patterns have changed substantially.

- R&D expenditures reached an estimated record-setting high of $206 billion in 1997. The rate of R&D investment in the mid-1990s was the highest it has been since the early 1980s, a welcome contrast to the situation in the early part of the decade, when increases in R&D spending failed to keep pace with inflation.
- Most of the R&D increases have been in the industrial sector. Industrial firms now provide two out of every three of the nation's R&D dollars (an estimated $133.3 billion in 1997) and perform three-fourths of the national R&D effort (an estimated $151.4 billion). The major part of industrial R&D is development and applied research rather than basic research.
- Total federal R&D obligations were an estimated $68.1 billion in FY 1997, 12 percent below the 1989 level (in inflation-adjusted dollars). The Federal Government has been steadily losing ground to industry as a source of R&D funds. In 1997, federal agencies provided 30 percent of

all R&D funds in the United States, down from 46 percent at the peak during the defense buildup a decade ago. This decline seems to have tapered off in the mid-1990s.

- Much of this decrease is a result of defense downsizing as priorities change, as well as attempts to control the budget deficit. The Department of Defense (DOD) share of federal R&D spending has been declining since the mid-1980s from its high of two-thirds of federal funds. In 1997, for the first time since the early 1980s, DOD is expected to account for less than half (48 percent) of the federal R&D total.
- The decrease in defense funds is reflected in federal funding of industrial R&D. Between 1987 and 1997, the federal share of total industry R&D performance declined dramatically—from 32 percent down to an unprecedented 14 percent.

Growth in federal support of academic R&D has slowed.

- In 1997, an estimated $23.8 billion was spent for R&D at U.S. academic institutions, representing 12 percent of the total national performance. Academia, however, has a much larger role in basic research, performing more than 50 percent of the nation's effort. Academic R&D activities are concentrated (67 percent) in basic research, with 25 percent in applied research, and only 8 percent in development.
- The majority of academic R&D expenditures in 1995 went to the life sciences, which accounted for 55 percent of total academic R&D expenditures. The next largest amount of academic R&D expenditures was for engineering—16 percent in 1995.
- The Federal Government continues to provide the majority (60 percent) of funds for academic R&D. Academia has experienced a slowdown in the annual rate of growth in federal support. The share of federal funding has declined in each of the broad S&E fields since 1975. The largest decline in the share of federal funding occurred in the social sciences, and the smallest declines were in computer sciences and environmental sciences.
- Federal agencies emphasize different S&E fields in the funding portfolios of academic research, and changes in federal R&D funding by agencies can have varying impacts on R&D funding and graduate education support in various fields. For example, changes in federal funding for defense R&D have affected academic engineering and computer science funding.

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"Since the war years, both Congress and the different administrations have shared the conviction that support of research in the Nation's universities and industries represented an investment in the national future."

D. Allan Bromley
Former Director
Office of Science and
Technology Policy

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"Further increases in the rate of international and intersectoral cooperation in science and engineering are not just desirable in the current environment, they are absolutely vital."

Joseph Bordogna
Acting Deputy Director
National Science Foundation

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Links are increasing between industry and academia.

- Industrial support to academic R&D has grown more rapidly than support from all other sources during the past two decades, but it still is only a fraction (7 percent) of the total.
- Industrial interaction with academia can be seen in more than just financial patterns. Coauthorship by industrial researchers has grown since the 1980s, and in particular with academia. Coauthorship between industrial researchers with researchers outside their sector rose from 27 percent in 1981 to 50 percent in 1995; about two-thirds of these collaborations involved academic researchers.
- Industrial firms are using academic research in their patent applications. The number of science article citations on U.S. patents increased from 8,600 in 1987 to 47,000 in 1996. The rise in citations held for all fields and for papers from all sectors, with the fastest growth in citations to biomedical research and clinical medicine.
- Academic patenting, especially in the biomedical fields, has increased rapidly. The number of academic patents, while small, increased more than sevenfold in just over two decades, from 250 annually in the early 1970s to more than 1,800 in 1995.

The largest increases in industrial R&D are occurring in the S&E-based industries.

- Companies classified in the electrical equipment industry experienced the largest absolute increases and the highest percentage increases in nonfederal R&D expenditures between 1991 and 1995. All of the increase occurred in the electronic components segment, which had a threefold increase in spending during this period.
- Pharmaceutical companies' R&D spending nearly tripled between 1985 and 1995. The most prominent trend in the drugs and medicines industry has been the increase in importance of biotechnology research; more than one-third of drug companies' R&D projects are primarily biotechnology related. In addition, the rapid growth of R&D dollars reflects the high cost of research directed toward developing cures and treatments for various diseases.

New funding mechanisms are gaining in prominence.

- Many countries have supplemented direct funding of R&D with fiscal incentives to increase the overall level of R&D spending and to stimulate industrial innovation. Almost all industrialized countries (including the United States) allow industry R&D expenditures to be 100 percent deducted from taxable income in the year they are incurred, and half of the countries (including the United States) provide some type of R&D tax credit.

- The pool of venture capital grew dramatically during the 1980s and emerged as an important source of financing for small innovative firms. Very little venture capital is actually disbursed to the "struggling entrepreneur" as "seed" money. In 1995, seed money accounted for only 6 percent of all venture capital disbursements; money for company expansion constituted 42 percent.

Cooperative R&D is now an important tool in the development and leveraging of S&T resources.

- There has been a major upswing in the number of inter- and intra-sectoral and international S&T partnerships since the early 1980s. The annual number of new research joint ventures between firms has been growing, with the largest increases occurring in 1995 and 1996.
- Technology transfer activities became an important mission component of federal laboratories in the late 1980s, and more than 3,500 new cooperative research and development agreements (CRADAs) were entered into between 1992 and 1995.

The service sector has increased in prominence, and information technologies are believed to have contributed to the country's shift to a service economy.

- The nonmanufacturing sector now accounts for approximately one-quarter of all R&D investment in the United States, considerably above the proportion it held in earlier decades. This higher profile is largely attributable to the growth of the information technologies (IT) and communication industries.
- An examination of employment patterns of scientists, engineers, and technicians in a portion of the nonmanufacturing sector (wholesale and retail trade, transportation, communications, and utilities) showed a downturn in employment in 1994 from the peak in 1991. The communications industry was one of the few experiencing an increase in employment of scientists and technicians between 1991 and 1994.
- Employment in IT-producing industries is projected by the U.S. Bureau of Labor Statistics to nearly double from 1986 to 2006. This expansion is based almost entirely on expected growth in computer and data processing services. However, employment in IT hardware industries has been declining. Nevertheless, as the demand for IT jobs spreads to other industries, IT occupations are expected to double over the shorter period of

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"Once experienced, the expansion of personal intellectual power made available by the computer is not easily given up."

Sheila Widnall

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"The more one observes,
the more clearly does he see
that it is in the soil of pure science
that are found the origins of all
our modern industry and commerce.
In fact, our civilization is wholly
built upon our scientific discoveries."

HERBERT HOOVER

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1996-2006. Since exact projections are always difficult, this should be taken as a general direction, not an exact level of employment.

- In the United States, software companies attracted more venture capital than any other technology area. In 1995, venture capital firms disbursed a total of $3.9 billion, of which 20 percent went to firms developing computer software or providing software services. Medical and health-related companies were second with 14 percent. By comparison, computer-related companies received just 7 percent of the venture capital distributed in Europe in 1995 and 5 percent in 1996, and European biotech firms received even less. European venture capital is primarily in industries such as machinery and equipment, fashion and leisure products.
- Between 1990 and 1995, the U.S. trade surplus in software technology doubled, and trade in computer-integrated manufacturing technologies generated a sizable surplus. However, since 1992, the United States has had trade deficits in three areas: opto-electronics, electronics, and computers and telecommunications. Large trade deficits with several Asian economies in these three advanced technology areas now exceed the trade surpluses generated from trade with other countries.
- Both South Korea and Taiwan continue to patent heavily in communication technologies and processes used to manufacture semiconductor devices, dynamic and static information storage, and display systems, among other technologies. Both are already major suppliers of computers and peripherals to the United States. These patent data show that they continue to develop new technologies and improvements that will likely support increased presence in the U.S. and global markets.

Science and technology affect our daily lives in many ways. The results of science and engineering findings surround us at work and at home, but the social and economic effects are often difficult to quantify and analyze. Scientific and technological literacy are important. Science and technology skills are increasingly required in many jobs. There is an increased emphasis on accountability and the importance of public understanding and awareness of science and technology. The public should be able to understand the scientific process and be knowledgeable about science and technology discoveries in order to participate more adequately in policy discussions. The information revolution is upon us and is exceedingly difficult to track, let alone understand its myriad implications and effects—both positive and negative. As we go into the next century, it is hard to visualize how our lives will be changed.

Use of information technology is increasing in the workplace, schools, and homes.

- The real net computing capital stock in the private sector was $155.8 billion in 1995. In many industries, the number of employees who use a computer at work is more than 50 percent; in the banking industry, it is 85 percent.
- Several comprehensive studies using a variety of data and methods indicate that there is an overall skill upgrading taking place in the labor force, a trend attributed to the greater use of IT in many occupations. Along with this increased use, the incidence of IT-related injury and employee surveillance in the workplace are on the rise, but the effects on individuals are uncertain.
- Most Americans—57 percent—use a computer at home or at work. This percentage has grown steadily during the last decade, and in 1997 fully 88 percent of college graduates in the United States indicated that they used a computer at work or at home, compared with 60 percent of high school graduates and 21 percent of individuals who did not complete high school.
- Nearly 32 million Americans have access to a home computer that includes a modem, and 18 percent of adults reported in 1997 that they had used an on-line computer service during the preceding year. This is a significant increase in home access to on-line resources since 1995.
- Nearly two-thirds of Americans with graduate education or a professional degree have a home computer with a modem, compared to 31 percent of those with a high school degree. About 41 percent of Americans with a graduate degree said that they use an on-line computer service compared to only 17 percent of those with a high school degree.

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"I cannot do it without counters."

WILLIAM SHAKESPEARE

THE WINTER'S TALE, IV, III

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"If we fail to ensure that our children have the technological resources they need to compete in an ever-changing information economy, our nation will be poorer for it."

VICE PRESIDENT ALBERT GORE, JR.

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- Approximately 16 percent of Americans reported having access to the World Wide Web from their home computers in 1997, and 12 percent of adults sampled—representing about 22 million people—indicated that they had previously tried to find some specific item of information on the Web. Around 6.5 million Americans said they had attempted to find health-related information, and about 8.8 million tried to find some scientific information (which would have included information about the environment, space, or computers).

- The use of, and access to, information technology in the classroom is seen as an important (but not sufficient) tool to enhance education, ensure equitable access, and develop computer skills for the overall population. By 1992, 80 percent of all K-12 schools had 15 or more microcomputers for instruction. In 1996, 85 percent of all schools had access to multimedia computers, 65 percent had Internet access, and 19 percent had a satellite dish. Internet linkages are not necessarily widely accessible within schools—in 1996, only 14 percent of instructional rooms had an Internet hookup.

- In fifth grade, more than half (58 percent) of the instructional use of computers is for teaching academic subject matter. By 11th grade, less than half (43 percent) of computer-based instruction is for content; 51 percent is for computer skills training. Meta-analysis of educational studies conducted between the late 1960s and the late 1980s consistently reveals positive effects of computer-based instruction at the K-12 level. Estimates of the order of magnitude vary, but one meta-analysis of 40 studies estimated learning advantages that ranged from the equivalent of one-third to one-half of a school year for K-6 education.

- Questions have been raised over the cost effectiveness of computer-based instruction relative to other forms of instruction. Additionally, significant inequity exists in educational access to computers and the Internet. Schools whose enrollments comprise primarily minority or economically disadvantaged students have one-third to three times less access to these technologies than do schools represented by white or nondisadvantaged students.

- Concerns about information privacy are growing larger and stronger. Two-thirds of the public said that protecting consumer information privacy was very important.

The issues of accountability and communication with the public are drawing increased emphasis.

- About one in five Americans think they are very well-informed about new scientific discoveries and about the use of new inventions and technologies. One in four Americans understands the nature of scientific inquiry well enough to be able to make relatively informed judgments about the scientific basis of results reported in the media.
- In 1997, 75 percent of Americans believed that the benefits of scientific research outweigh any present or potential harms. Despite their positive views of scientific research, Americans are deeply divided over the development and impact of several important technologies, including nuclear power and genetic engineering.
- American adults express a high level of interest in new scientific discoveries and in the use of new inventions and technologies. The public is interested in knowing what is happening in science and technology, and the scientific community needs to communicate its work ever more clearly and effectively.

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"Public opinion is everything. With public sentiment nothing can fail; without it, nothing can succeed."

Abraham Lincoln

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